

PROJECT of ISTC 2172

BUSINESS TRIP REPORT ON PSTG PROGRAMME - 2003

**TECHNICAL TRAINING ON HIGH-ORDER SPECTRAL ANALYSIS AND
THERMAL ANEMOMETRY APPLICATIONS**

Term: August 18 – September 5

Participants:

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Location:

NASA Langley Research Center, Hampton, Virginia

September 2003

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Team Members

The technical training entitled “*High-Order Spectral Analysis and Thermal Anemometry Applications*” took place at the NASA Langley Research Center, Hampton, Virginia during the period August 18, 2003 to September 5, 2003. The following personnel from the Institute of Theoretical and Applied Mechanics, Russian Academy of Sciences, Siberian Branch who were earlier involved in the ISTC projects № 1863 and № 2172 participated in the training:

Prof. A. A. Maslov, Deputy Director, ITAM and Head, Hypersonics Flow Laboratory
Dr. A. N. Shiplyuk, Senior Researcher, Hypersonics Flow Laboratory
Dr. A. A. Sidorenko, Senior Researcher, Hypersonics Flow Laboratory
Mr. D. A. Bountin, Research Assistant, Hypersonics Flow Laboratory

Initially Dr. T. Poplavskaya, Senior Researcher, Mr. V. Aniskin, Research Assistant, and E. Burov, postgraduate student, were also to be members of the team. However they were unable to participate for a variety of reasons. Dr. Poplavskaya and Mr. Aniskin were denied a visa by the US Embassy in Moscow. Mr. Burov could not participate because of family obligations. This reduction of the number of participants was co-ordinated with ISTC and NASA Langley.

Objective and Schedule

The topics of thermal anemometry and high-order spectral analyses were the subject of the technical training. Specifically, the objective of the technical training was to study: (i) the recently introduced constant voltage anemometer (CVA) for high-speed boundary layer; and (ii) newly developed high-order spectral analysis techniques (HOSA). Both CVA and HOSA are relevant tools for studies of boundary layer transition and stability.

The initial schedule of the technical training is shown in Appendix 1. However, on account of family bereavement, Prof. Ndaona Chokani was unable to participate in the first week of the course. The program schedule was therefore modified to focus on preparations for the wind tunnel experiments during the first week, as well as focused discussions with NASA scientists. This change could be accommodated because of smaller number of the team members. During the second week of the technical training, the lectures were alternated with the laboratory demonstrations of the CVA in wind tunnel experiments; an individual teaching approach was used to provide the instruction in HOSA. Therefore the objectives of the technical training “High-order spectral analysis and thermal anemometry applications” were completely fulfilled.

Summary of Technical Training

In individual meetings the team had round-table discussions with several staff including Prof. Chokani of NC State University, Fig. 1, the NASA Langley Chief Scientist, Senior Scientist from the Computational Modeling and Simulation Branch, and Senior Researcher from the Flow Physics and Control Branch. One of the more interesting round-table discussions was with Mr. D. M. Bushnell, Chief Scientist, during which in addition to perspectives of the future for rocketry and aircraft, the application of new technologies in the very promising area of personal aerospace vehicles (PAV) were discussed. PAV are being considered as a replacement for automobiles. Micro aerospace vehicles were also discussed. At a meeting with Dr. M. R. Malik of the Computational Modeling and Simulation Branch, various methods of boundary layer transition control by means of ultrasounds absorptive coatings; in addition aspects of hypersonic boundary layer receptivity to acoustic disturbances were discussed. Mr. Thomas J. Horvath of NASA Langley gave a lecture to the team on the hypersonic transition studies in the Aerothermodynamics Branch at NASA Langley. In Fig. 2, Mr. Horvath can be seen describing

the methods of heat flux measurements used at NASA. Mr. S. P. Wilkinson of the Flow Physics and Control Branch showed the team around wind tunnel facilities engaged in studies of flow physics; the use of an oscillatory plasma surface for turbulent drag reduction was also demonstrated.¹ Prof. Maslov gave a seminar entitled “Hypersonic Boundary Layer Stabilization by Ultrasonically Absorptive Surface with Regular Microstructure.” NASA scientific staff attended this seminar. While the seminar of Prof. Maslov took place at NASA Langley, the round-table discussions took place at the National Institute of Aerospace (NIA). NIA is adjacent to NASA Langley. NIA is equipped with modern office equipment, computers, a library, meeting rooms and lecture theaters, which were made available to the team.



Fig. 1. Round table discussion on bispectral analysis techniques. From l. to r.: Dr. A. Siderenko, Prof. A. Maslov, Mr. D. Bountin and Prof. N. Chokani.

The lectures and discussion on the bispectral analysis technique (one method of HOSA) were undertaken at NIA, Fig. 3. The team brought on their visit experimental data that were obtained in the T-326 tunnel at ITAM. The analyses of these data were quite insightful. A manuscript for an archival publication is now in preparation; Shiplyuk, A. N., Bountin, D. A., Maslov, A. A. and Chokani, N., “Subharmonic Resonances in Hypersonic Laminar Boundary Layers,” in preparation for *Journal of Fluid Mechanics*. Additionally a second publication is also in preparation for the 42nd AIAA Aerospace Sciences Meeting to be held in Reno, Nevada; Shiplyuk, A. N., Bountin, D. A., Maslov, A. A. and Chokani, N., “Nonlinear Aspects of Hypersonic Boundary Layer Stability on a Porous Surface.” In relation to publications in archival literature, it was noted that Prof. Chokani is the member of the editorial staff of international scientific journals published in USA. Therefore a lecture devoted to paper preparation for publication in USA scientific journals was presented, and the grammatical and stylistic standards illustrated by editing two papers^{2,3} prepared by team members for the AIAA’s *Journal of Spacecraft and Rockets*.

¹Wilkinson, S. P., “Investigation of an oscillating surface plasma for turbulent drag reduction,” AIAA Paper 2003-1023

²A. Maslov, D. Buntin, A. Sidorenko, and A. Shiplyuk, “Mach 6 boundary layer stability experiments on sharp and blunted cones,” manuscript in preparation for *Journal of Spacecraft and Rockets*.



Fig. 2: Mr. T. J. Horvath of NASA Langley discusses methods of heat flux measurements

The primary portion the laboratory training took place in the 20-inch Mach 6 wind tunnel at NASA Langley. In order to provide a metric of success for the training the team and Prof. Chokani were tasked with performing freestream measurements in the wind tunnel. These measurements are relevant to the hypersonic transition research in the Aerothermodynamics Branch, which were discussed by Mr. Horvath. The team brought from ITAM its recently developed hybrid constant current-constant temperature anemometer (ITAM CCA). However on account of unanticipated difficulties adjustments needed to be made to the ITAM CCA, Fig. 4. The difficulties arose due to the weak signals that resulted from unexpectedly high levels of electromagnetic, Fig. 5. The adjustments were successful, and the measurements made with the ITAM CCA were subsequently compared with the Tao Systems CVA that was operated by Prof. Chokani. A representative comparison of free stream spectra is shown in Fig. 6. A more detailed analysis of the comparison between CVA and CCA is underway; it is proposed to prepare a paper is presentation at the next summer meeting of the AIAA.⁴

³A. Maslov, S. Mironov, and V. Aniskin, "Hypersonic Shear Layer Stability Experiments," manuscript in preparation for Journal of Spacecraft and Rockets.

⁴C. B. McGinley, N. Chokani, A. N. Shpielyuk, A. A. Sidorenko "Comparison of CVA and CCA Measurements in the Freestream of a Hypersonic Wind Tunnel," manuscript in preparation for AIAA 2004 Fluid Dynamics Conference, Portland OR.

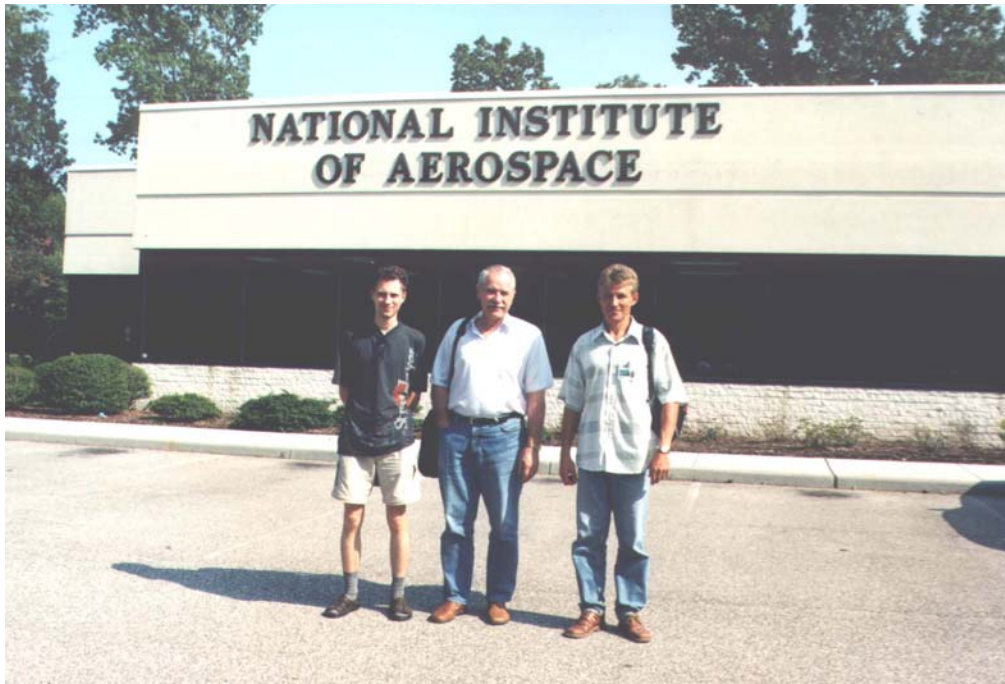


Fig. 3. The National Institute of Aerospace (NIA) provided access to computers, a library, meeting rooms and lecture theaters for the team.



Fig. 4: Dr. A. Sidorenko and Dr. A. Shiplyuk make adjustments to the ITAM CCA for measurements in the NASA Langley 20-inch Mach 6 tunnel



Fig. 5: Dr. R. King, Ms. C. McGinley, Dr. A. Shiplyuk and Dr. A. Sidorenko discuss results of the CVA and ITAM CCA comparisons during the practical training

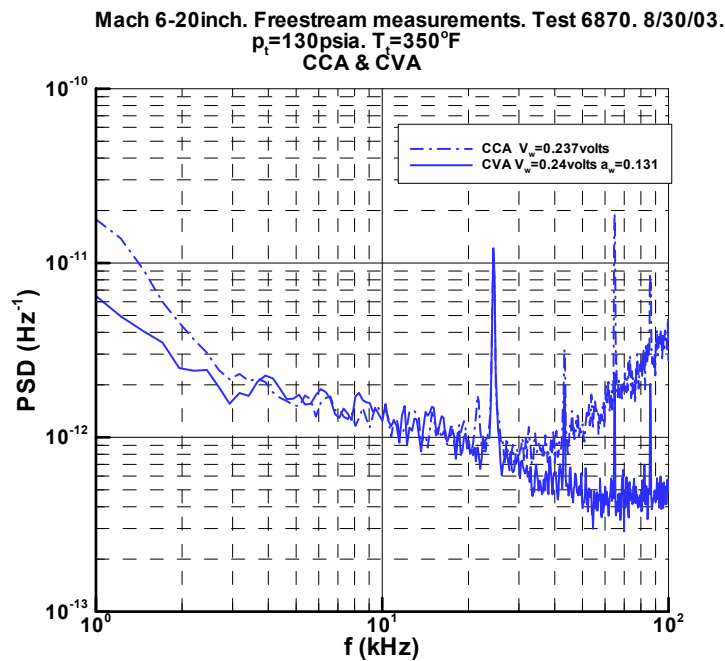


Fig. 6: Preliminary comparison of CVA and CCA measurements.

The present experiments provide a unique experience to operate the CVA; this anemometer-type is inaccessible out the US. The preliminary comparison of the data obtained by CVA and CCA has show relatively good agreement. However, the frequency range of the CCA appears to be smaller than the frequency range of the CVA.



Fig. 7: The team at the conclusion of the experiments in the control room of the NASA Langley 20-inch Mach 6 tunnel. Front row: Prof. N. Chokani (NC State) and Ms. G. Gleason (NASA). Back row: Ms. C. McGinley (NASA), Dr. R. King (NASA), Mr. T. Horvath (NASA), Dr. A. Shipluk (ITAM) and Mr. S. Berry (NASA).



Fig. 8: After the conclusion roundtable discussion.

At the conclusion of the technical training at NASA Langley a roundtable discussion (fig. 8) was held to review the two weeks of activity. Dr. M. Choudhari of NASA noted the successful

accomplishment of the experiments and outlined possible opportunities for continued cooperation between ITAM and NASA. In these discussions, the complementary measurements capabilities at ITAM and NASA, new methods of digital signal processing and the experimental facilities available at both NASA and ITAM were considered in detail. As the result of the discussions, Prof. Maslov and Prof. Chokani prepared and submitted to NASA Langley the white paper, "Hypersonic Laminar Flow Control on Hyper-X Configuration." This is included as Appendix 2.

Following the technical training Prof. Chokani organized additional scientific meetings for the team. These included visits to Duke University, Durham NC (where Prof. Chokani moves in January 2004) and the Civilian Research and Development Foundation in Washington DC. At Duke University meetings were held with Prof. Kristina Johnson, Dean, School of Engineering, Prof. Kenneth Hall, Chair, Mechanical Engineering and Materials Science, and Prof. April Brown, Chair, Electrical and Computer Engineering. In Washington DC, a meeting was held with Mr. Kevin D. Wolf, Program Manager. At this last meeting the reviews of the proposal "Development of Nano-Scale Hot Tubes For Flow Measurements," submitted by Profs. Chokani and Maslov were discussed; the proposal received a meritorious rating but was not selected for funding in the current fiscal year.

In addition the scientific aspects of the technical training, a cultural activities program was organized to provide the participants with more familiarization with the US. These activities included:

- excursion to the Smithsonian National Air & Space Museum, Washington DC
- visit to NC Zoo, Asheboro, North Carolina
- visit to Duke University Primate Research Center, Durham, North Carolina
- visit to a Durham Bulls baseball game, Durham, North Carolina

Conclusions

On training completion certificates were delivered to the participants.

1. The program of the training is completely fulfilled. Set objects are achieved. Participants have received experience of work with the modern experimental equipment and signal processing methods.
2. The first detailed measurements of free stream fluctuations in 20-inch tunnel (NASA Langley) are carried out.
3. As the result of the training ending three publications are prepared.
4. The joint project "Hypersonic laminar flow control on Hyper-X configuration» is prepared.
5. A series of the important meetings with NASA, Duke University and CRDF management took place.

Acknowledgements

The participants of the technical training are grateful to ISTC and EOARD for the financial support. The participants wish to thank Prof. Ndaona Chokani (NC State University), Dr. Meelan M. Choudhari, Dr. Rudolph A. King and Ms. Catherine B. McGinley (NASA Langley) for the organization and realization of the technical training. The assistance of the technical staff of the 20-inch Mach 6 tunnel at NASA Langley is also gratefully acknowledged.

Appendix 1. Proposed Schedule of Lectures and Laboratory Sessions

1	Lecture <i>Complex digital demodulation</i> (Lector Prof. Ndaona Chokani) Tutorial <i>Overview of NASA Langley transition program</i> (Lector Dr. Meelan Choudhari)	(two hours) (four hours)
2	Lecture <i>Joint time-frequency analysis, including short time Fourier transform</i> (two hours) (Lector Prof. Ndaona Chokani) Tutorial <i>Overview of NASA Langley high-speed wind tunnels</i> (Lector. Dr. Rudy King)	 (four hours)
3	Lecture <i>Fourier bispectra</i> (Lector Prof. Ndaona Chokani) Tour of Mach 3.5 quiet tunnel and supersonic wind tunnel (Lector Dr. Rudy King)	(two hours) (four hours)
4	Lecture <i>STFT bispectrum</i> (Lector Prof. Ndaona Chokani) Laboratory assignment Introduction to CVA (Lector Prof. Ndaona Chokani))	(two hours) (four hours)
5	Lecture <i>Wavelet bispectrum</i> (Lector Prof. Ndaona Chokani) Tutorial <i>Hot-wire thermal lag and visit to probe calibration test facilities</i> (Lector Dr. Rudy King)	(two hours) (four hours)
6	Lecture <i>Linear & quadratic transfer functions</i> (Lector Prof. Ndaona Chokani) Tutorial <i>Hardware time compensation</i> (Lector Prof. Ndaona Chokani) Laboratory assignment Preparation of experiment in 20inch tunnel (Lector. Dr. Rudy King)	(two hours) (two hours) (two hours)
7	sight-seeing	
8	Tutorial <i>Amplitude and phase response</i> (Lector Prof. Meelan Choudhari) Laboratory assignment Execution of test in 20 inch tunnel (Lector. Dr. Rudy King)	(two hours) (four hours)
10	Tutorial <i>Electronic testing of CVA</i> (Lector Prof. Ndaona Chokani) Laboratory assignment Execution of test in 20 inch tunnel (Lector. Dr. Rudy King)	(two hours)
11	Tutorial <i>Anemometer noise</i> (Lector Prof. Ndaona Chokani) Laboratory assignment Execution of test in 20 inch tunnel (Lector. Dr. Rudy King)	(four hours) (two hours)
12	Tutorial <i>Data acquisition systems</i> (Lector Prof. Ndaona Chokani) Laboratory assignment Execution of test in 20 inch tunnel (Lector. Dr. Rudy King)	(four hours) (two hours)
13	Discussion of the future collaboration (Prof. Ndaona Chokani and Dr. Meelan Choudhari)	

Appendix 2: White paper prepared following conclusion of ISTC training.

**White Paper
submitted to the
NASA Langley Research Center,
Hampton VA**

entitled

Hypersonic laminar flow control on a Hyper-X configuration

submitted by

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**Date:
September 5, 2003**

Introduction

The first practically realizable method for the control of transition in the hypersonic laminar boundary layer has been demonstrated in a series of recent experiments at ITAM.¹⁻³ These experiments – supported by companion linear stability computations – show that both random and regular ultrasonically absorptive porous coatings have a dramatic stabilizing effect on the dominant second mode. These studies have been performed on a right-circular cone configuration, which though of fundamental interest, does not represent a configuration of practical interest. Therefore the primary objective of the proposed work is to examine – and document – the effectiveness of regular ultrasonically absorptive porous coatings on delaying transition on a more realistic configuration. It is proposed that this realistic configuration be the forebody and upper surface of the Hyper2000, since this geometry is unclassified and available to the general public.

A secondary objective of the proposed work is to generate experimental data that are of a suitable quality for numerical verification. In previous work, transition data on a right-circular cone at zero degrees angle-of-attack were obtained in the GALCIT T-5 shock tunnel at Caltech.⁴ As it is well known that the freestream disturbance environment of the wind tunnel has an influence on the transition location, we propose that the realistic configuration, equipped with ultrasonically absorptive porous coatings, be tested at both ITAM and NASA Langley. This configuration shall also be tested at angle-of-attack since the flight trajectory of air vehicle may involve phugoid motion. The freestream disturbance environment in the ITAM facilities are routinely documented; this potential capability in the NASA 20-inch Mach 6 facility has recently been demonstrated. Therefore in addition to freestream disturbance measurements, we propose to obtain disturbance measurements in the boundary layer, and also apply bispectral analysis techniques to clarify the mechanisms of control.⁵⁻⁷

Approach

A three-year plan of work to investigate the effectiveness of the ultrasonically absorptive porous coatings for transition control on the Hyper2000 is therefore proposed. This geometry is representative of the more general class of Hyper-X vehicles. We propose to conduct this work plan in coordination with researchers in the Aerodynamics, Acoustics and Aerothermodynamics Competency at NASA Langley Research Center. The main elements of this proposed plan are:

1. Build multipurpose models of the forebody of the Hyper2000 that may be tested at ITAM and NASA; the models shall be equipped with interchangeable inserts of the ultrasonically absorptive porous coatings.
2. Use computational methods – linear stability analysis and transition prediction – to provide preliminary predictions of the boundary layer stability and transition.
3. Obtain transition measurements – at ITAM and NASA – using surface heat flux gages.
4. Obtain disturbance measurements – at ITAM and NASA – to clarify the structure of the flow.
5. Apply bispectral methods to clarify the mechanisms of the control.
6. Compare the different – ITAM and NASA – experimental measurements, and use the computational methods to predict the effects at flight conditions.

Some significant aspects of this approach include the following. The proposed test article is of practical relevance as this geometry is encountered in the class of Hyper-X vehicles; therefore this study is of direct relevance to the mission of the NGLT program at NASA. The T-303 impulse facility at ITAM that can be equipped with a Mach 6 or Mach 10 nozzle shall be used; this facility is chosen as it is of comparable size to the NASA Langley 20-inch Mach 6 tunnel.

The flow conditions and model geometry at ITAM and NASA shall be identical; this shall enable the identification of any facility dependent phenomena. The disturbance measurements acquired in the proposed work will provide the amplitude, growth rates, spectra, etc. of the boundary layer disturbances. These data shall be obtained using an artificial disturbance generator. The use of an artificial disturbance generator shall permit the initial amplitude and frequency of the disturbances to be specified; therefore the disturbance measurements will be suited for numerical verification.

Proposed schedule

In year one, the primary focus shall be on the design and fabrication of two multipurpose models and an improved artificial disturbance generator. One model shall be equipped with heat flux gages to provide transition measurements; the second model shall be equipped with large bandwidth ($\sim 1\text{MHz}$) thermopile gages to provide disturbance measurements. Both models shall be equipped with interchangeable inserts, with and without ultrasonically absorptive porous coatings. The design of the models shall be based on the technique developed in Ref. 8. The characterization of the nonlinear wave processes shall require the development of an improved artificial disturbance generator, which is capable of generating two-dimensional disturbances; this disturbance generator shall be built in year one. Preliminary stability and transition calculations shall precede the design and fabrication of the model. The tasks in year one shall conclude with transition measurements at ITAM.

	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Preliminary/final calculations	xxx			x			xx				xx	
Design of model	xx				x							
Manufacture of model		xxx	xxx		x							
Manufacture & calibration of gages			xx									
Transition measurements				xx					xx			
Data processing				xx			xx		x		xx	
Report preparation				x				x				x
Data acquisition programming					x	x						
Disturbance measurements						xx						
NASA experiments							x			xx	x	

In year 2 transition and disturbance measurements shall be conducted at NASA and ITAM respectively. The transition measurements made in year 2 at NASA shall be compared with the transition measurements made in year 1 at ITAM. A second model shall be manufactured in year 2, and disturbance measurements will be obtained using surface-mounted, large bandwidth thermopile gages; the focus of these measurements is to understand the wave structure and nonlinear interactions. The subsequent disturbance measurements made at NASA in year 3, using hot-wire measurements shall be similarly focused; however the ability to obtain the off surface hot-wire measurements in the 20-inch Mach 6, means that these hot-wire measurements are a key element of the proposed work plan. In the first half of year 3, transition measurements involving parametric studies of the effects of angle of attack and unit Reynolds number shall be conducted at ITAM. A similar parametric study shall be conducted at NASA in the second half of year 3. The preliminary calculations made in year one, shall be further refined in year 3, using the experimental data – obtained at NASA and ITAM – as reference conditions. Furthermore following verification against the experimental data, the verified computational methods shall be used to examine the scaling – to full-scale – effects on the effectiveness of ultrasonically absorptive porous coatings. The experimental database will be suited for the verification of theoretical models, the analysis of the linear and nonlinear stages of transition on the

ultrasonically absorptive porous coatings, and will provide parametric effects on transition. The expected outcome of this proposed plan of work is that we shall therefore have the basis for the design of other realistic configurations that incorporate this novel technology for the control of hypersonic transition. The proposed tasks and work plan for the three-year period of work are shown in the table above.

Preliminary cost estimates

The related cost distribution for the three-year research program is \$65,000/year for the tasks described in years 1-3 above. These costs at ITAM include personnel expenses, equipment, research, supplies and materials, wind tunnel usage, travel, and overhead.

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